Gravitational Physics via Millimeter Accuracy Data from APOLLO

Completed Technology Project (2018 - 2020)

Project Introduction

Gravity--the most evident force of nature--is in fact the weakest of the fundamental forces, and consequently the most poorly tested. Einstein's general relativity, currently our best description of gravity, is fundamentally incompatible with quantum mechanics and is likely not the final word on gravity. A modified theory would predict small solar system deviations that could have profound consequences for our understanding of the Universe as a whole. Lunar laser ranging (LLR), in which short laser pulses launched from a telescope are bounced off of reflectors placed on the moon by U.S. astronauts and Soviet landers, has for decades produced some of the leading tests of gravity by mapping the shape of the lunar orbit to high precision. Since 2006, an experiment called APOLLO (the Apache Point Observatory Lunar Laser-ranging Operation) has been collecting the best LLR data in the world, in terms of both data volume and precision. In the last year, we have added the capability to guarantee accuracy of APOLLO data at the millimeter level. We propose a campaign to collect the first-ever set of millimeter-accurate LLR data using APOLLO. Lunar ranging provides the best tests of a number of gravitational phenomenologies, including tests of the strong equivalence principle, the time-rate-of-change of Newton's gravitational constant, gravitomagnetism, the inverse-square law, and many others. The improvements made possible by APOLLO will either expose new physics or establish more stringent constraints on the foundation of gravity. Besides its data quality, APOLLO's ability to range to all five lunar reflectors on timescales of much less than one hour dramatically improves our ability to gauge the orientation and distortion of the Moon. This information produces insights into the interior structure and dynamics of the Moon--itself allowing a more precise determination of the path for the center of the Moon, which is needed for fundamental tests of gravity. Similarly, high-accuracy range measurements, together with data from a superconducting gravimeter at the Apache Point Observatory and from a high-quality Global Positioning System (GPS) station 2.5 km away, will greatly improve our understanding of the instantaneous location of the Observatory with respect to the Earth's center of mass (needed for the gravitational test) by exposing subtle Earth dynamics that must be incorporated into the model. In addition to dramatic improvements in the classical gravitational tests listed above, APOLLO will permit exploration of new ideas in physics relating to dark energy, extra dimensions, and violations of Lorentz Invariance: very much in line with NASA's mandate to discover how the Universe works. The proposed work will benefit the broader community in a number of ways. On the intellectual front, improving our knowledge of gravity informs a diverse range of cosmologists, astrophysicists, particle physicists, and string theorists. The effort would also contribute to Earth and planetary science, especially via the inclusion of the superconducting gravimeter data. APOLLO will continue its strong record supporting undergraduate and graduate researchers, including women and minorities. The proposal includes support for two graduate students and for undergraduate research. The investigators routinely engage in outreach

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Organizational Responsibility

Responsible Mission Directorate:

Science Mission Directorate (SMD)

Lead Organization:

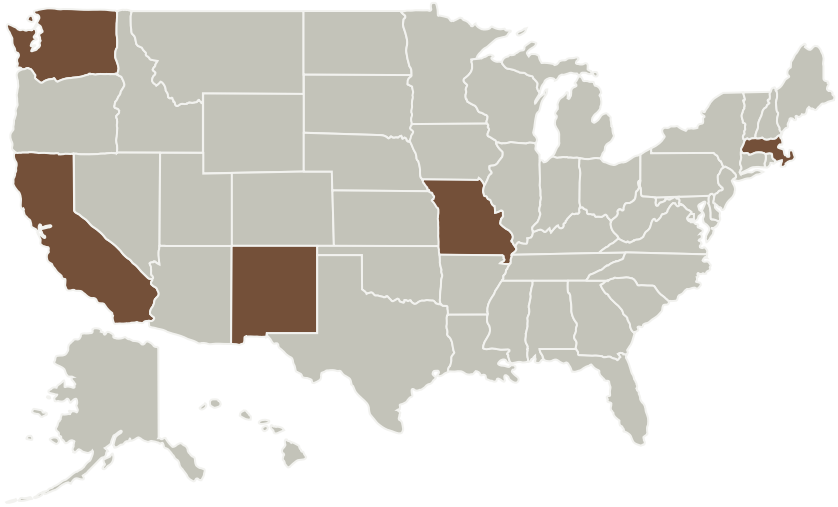
University of California-San Diego (UCSD)

Responsible Program:

Astrophysics Research and Analysis

activities associated with the programs Reach for Tomorrow, Tech Trek, and the Annenberg Foundation's Physics of the 21st Century. These programs target underprivileged middle school kids, middle school girls who show scientific interest, and high school teachers, respectively. APOLLO has been effective at public outreach and education via news articles, magazine articles, radio interviews, and appearances on popular television shows. This level of media attention should continue into the future, given the appealing combination of tests of Einstein's gravity, the legendary lunar landings, and remarkable technology.

Primary U.S. Work Locations and Key Partners



Project Management

Program Director:

Michael A Garcia

Program Manager:

Dominic J Benford

Principal Investigator:

Thomas W Murphy

Co-Investigators:

Eric Adelberger
Russet J Mcmillan
James B Battat
Barbara Heironimus
David J Crossley
Christopher W Stubbs

Technology Areas

Primary:

- TX12 Materials, Structures, Mechanical Systems, and Manufacturing
  - TX12.2 Structures
    - TX12.2.4 Tests, Tools and Methods

Target Destination

Outside the Solar System

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Organizations Performing Work	Role	Type	Location
University of California-San Diego(UCSD)	Lead Organization	Academia	La Jolla, California
Astrophysical Research Consortium	Supporting Organization	Industry	
Harvard University	Supporting Organization	Academia	Petersham, Massachusetts
Saint Louis University	Supporting Organization	Academia	Saint Louis, Missouri
University of Washington-Seattle Campus(UW)	Supporting Organization	Academia Asian American Native American Pacific Islander (AANAPISI)	Seattle, Washington
Wellesley College	Supporting Organization	Academia	Wellesley, Massachusetts

Primary U.S. Work Locations	
California	Massachusetts
Missouri	New Mexico
Washington	